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Risk Analysis and Mitigation of Flash Flood in Ijen Sub-District, Bondowoso

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ABSTRAK

Badan Penanggulangan Bencana Daerah (BPBD) mencatat bahwa Kabupaten Bondowoso pernah mengalami tiga kali kejadian banjir bandang sepanjang tahun 2020 – 2024 yang seluruhnya terjadi di Kecamatan Ijen. Bencana ini menyebabkan jalan desa tertutup lumpur, kerusakan pada rumah warga, infrastruktur, dan kandang ternak. Namun, terdapat ketidaksesuaian dalam dokumen perencanaan tata ruang di tingkat kabupaten maupun provinsi masih. Sehingga upaya penanggulangan bencana belum dapat dilakukan secara optimal. Oleh karena itu, analisis risiko dan mitigasi bencana diperlukan untuk mengurangi risiko yang ada serta memberikan rasa aman dan nyaman bagi masyarakat. Penelitian ini bertujuan untuk menganalisis tingkat risiko banjir bandang dan menyusun upaya mitigasi yang relevan. Pendekatan yang digunakan meliputi analisis spasial dengan Sistem Informasi Geografis (SIG) untuk memetakan tingkat risiko bencana dan analisis Delphi yang melibatkan 6 ahli dalam 2 kali putaran iterasi menggunakan kuesioner untuk memberikan rekomendasi kegiatan mitigasi yang tepat. Penelitian ini juga melanjutkan hasil studi sebelumnya terkait manajemen tanggap darurat dan keterlibatan pemangku kepentingan dalam tahap prabencana di Kecamatan Ijen. Hasil analisis menunjukkan bahwa 52,11% wilayah termasuk dalam kategori risiko rendah, 44,12% kategori sedang, dan 3,77% kategori tinggi yang seluruhnya tersebar di 6 desa. Tingkat risiko yang didominasi kelas rendah disebabkan oleh faktor tutupan lahan yang sebagian besar berupa hutan, kepadatan penduduk yang rendah, sebaran permukiman penduduk yang terkonsentrasi, dan adanya kelompok Desa Tanggh Bencana (DESTANA) dalam meningkatkan kapasitas wilayah untuk menghadapi bencana. Selanjutnya, rekomendasi kegiatan mitigasi dibagi menjadi mitigasi struktural dan mitigasi nonstruktural. Penelitian ini diharapkan dapat memberikan informasi, pertimbangan, dan rekomendasi dalam penanggulangan bencana serta kebijakan tata ruang di Kabupaten Bondowoso khususnya terkait banjir bandang. Selain itu, metode dan parameter yang digunakan dapat dikembangkan lebih lanjut untuk memahami karakteristik wilayah rawan bencana secara lebih mendalam.

Kata kunci: Risiko, Mitigasi, Banjir Bandang, GIS, Delphi

ABSTRACT

The Regional Disaster Management Agency (BPBD) reported that Bondowoso Regency experienced three flash flood incidents between 2020 and 2024, all of which occurred in Ijen Subdistrict. These disasters covered village roads with mud and damaged residents' houses, infrastructure, and animal cages. However, inconsistencies in spatial planning documents at the regency and provincial levels still make disaster management less optimal. Risk analysis and disaster mitigation are needed to reduce existing risks and provide a sense of safety and comfort for the local community. This study aims to analyze the level of flash flood risk and develop relevant mitigation measures. The approaches used included spatial analysis using a Geographic Information System (GIS) to map disaster risk levels and a Delphi analysis involving 6 experts in 2 rounds of iterations using a questionnaire to provide recommendations for appropriate mitigation measures. This research also continues previous studies related to emergency response management and stakeholder involvement in the pre-disaster stage in Ijen Sub-District. The results of the risk level of flash floods show that 52,11% are in the low class, 44,12% are in the medium class, and 3.77% are in the high class, spread across 6 villages. Furthermore, recommendations for mitigation activities are divided into structural mitigation and nonstructural mitigation. This study is expected to provide information, considerations, and recommendations for disaster management and spatial planning policies in Bondowoso Regency, particularly regarding flash floods. In addition, the methods and parameters used can be further developed to understand the characteristics of disaster-prone areas better.

Keywords: Risk, Mitigation, Flash floods, GIS, Delphi

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1. INTRODUCTION

A disaster is an unexpected event that can threaten human life. Flash floods are different from floods in general because they have high destructive power and can damage anything within their path, carrying various materials such as sand, soil, mud, stones, and wood. Flash floods are a hydrometeorological disaster that is unpredictable because they occur suddenly, move at high speeds, and produce waves 3–6 meters high (Badan Nasional Penanggulangan Bencana, 2023).

Flash floods are likely to occur in upper river basins or mountainous areas with steep slopes that are prone to landslides following heavy rainfall. This leads to a buildup of trapped water that continues to rise beyond the available capacity. Soil conditions that cannot absorb water due to land-use changes cause water to overflow rapidly along the slopes. Consequently, river flows carrying large amounts of suspended sediment pass through valleys that have been converted into residential areas and infrastructure development zones (Pinos & Timbe, 2020).

The Regional Disaster Management Agency of Bondowoso Regency recorded data between 2020 – 2024 showing that 3 (three) incidents of flash floods have occurred in Bondowoso Regency. All three events occurred in Ijen Sub-District. Several factors, including high rainfall intensity, triggered this disaster. The Djuanda Meteorological Station recorded that during the events on January 29, 2020, March 14, 2020, and February 12, 2023, Bondowoso Regency was under a weather alert for heavy rain of approximately 50 mm–100 mm per day. In addition, the Bondowoso Regency Regional Disaster Management Agency also reported that deforested areas resulting from land-use conversion and wildfires around Mount Raung and Mount Suket exacerbated the flash floods that specifically struck the villages of Kalisat and Sempol. This is corroborated by Perum Perhutani's Bondowoso, which states that approximately 800 hectares of forest in Ijen Subdistrict have been converted into illegal plantations (Land cover map of Ijen Sub-District is shown in Figure 1). The impacts included injuries, damage to 316 residential homes, damage to 40 animal pens, damage to village infrastructure, the loss of 864 livestock, 7 km of village roads submerged in mud, and 10 hectares of farmland submerged (Putranto, 2020).

Therefore, to minimize the negative impact of disasters, mitigation activities need to be optimized as a predisaster stage in disaster management. These activities must be accommodated in spatial planning documents. However, in the spatial plan of the Bondowoso Regency for 2024 – 2044, it did not specifically explain the risk level of flash floods. In the 2023 Disaster Risk Assessment of Bondowoso Regency, Ijen Subdistrict has a low flash flood risk covering an area of 312.3 hectares and a medium risk covering an area of 2.77 hectares. Meanwhile, the spatial plan of East Java Province for 2023 – 2043 and the Disaster Risk Assessment of East Java Province for 2023 – 2026 indicate a relatively high flash flood risk in Bondowoso Regency. This inconsistency can make disaster management efforts not optimal.

Risk analysis was performed via a Geographic Information System (GIS) with scoring and overlay techniques in ArcGIS software (Hidayah et al., 2022). his analysis measures hazard, vulnerability, and capacity to identify the risk of flash floods in Ijen Sub-District. The resulting risk level will be the basis for determining disaster mitigation activities via Delphi analysis, measured through a Likert scale questionnaire. Delphi analysis is the process of gathering information with a rotation system that involves experts reaching a consensus or agreement (Ariyaningsih et al., 2021).

Research on risk analysis and disaster mitigation builds on previous research on stakeholder involvement in emergency response management in Ijen Sub-District by detailing predisaster-stage management in terms of objectives, methods, and outcomes (Rustinsyah & Prasetya, 2023). This is important not only for reducing the risk of disasters but also to provide a sense of security and comfort to tourists. By knowing the level of disaster risk and mitigation, disaster management can be more directed, effective, and sustainable in the future. This study aims to provide information, considerations, and recommendations regarding disaster risk management, as well as the development of spatial planning policies based on disaster mitigation in Bondowoso Regency.

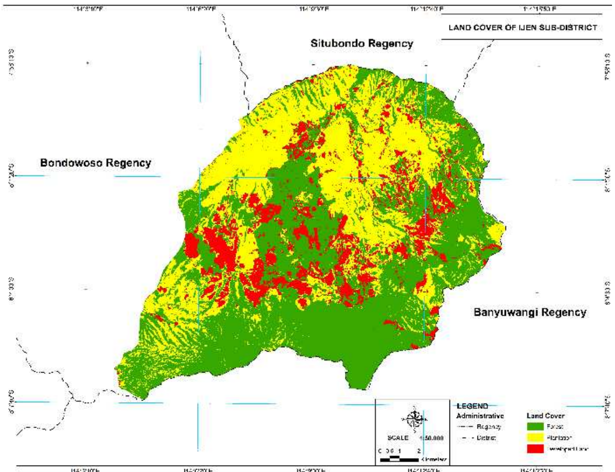

Figure 1. Land Cover of Ijen Sub-District

2. DATA AND METHODS

2.1. Location

The research location is in Ijen Sub-District, Bondowoso Regency. It is located at 7°58'10'' S - 8°7'40" S and 114°4'10'' E - 114°14'40'' E. Ijen Sub-District is the easternmost area of Bondowoso Regency, with an area of approximately 219.135.500 m^2 and an altitude of 1,130 meters above sea level.

The research location map is shown in Figure 2. Ijen Sub-District is surrounded by:

A. North: Situbondo Regency
B. South: Banyuwangi Regency
C. East: Banyuwangi Regency
D. West: Tlogosari Sub-District, Sumberwringin Sub-District, Botolinggo Sub-District, and Cermee Sub-District

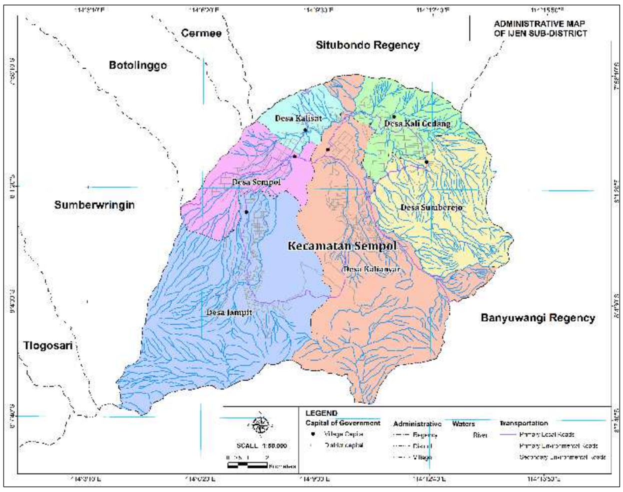

Figure 2. Research Location Map

2.2. Data

The research data used consisted of primary data and secondary data. Primary data were obtained through field observations and interviews to get opinions from questionnaires with experts to determine disaster mitigation activities. Moreover, secondary data were obtained through a literature review of institutional documents to obtain data on hazard, vulnerability, and capacity variables. The details of the data used are described in Figure 3.

2.3. Data Analysis

2.3.1. Spatial analysis

Spatial analysis is a method of processing, modeling, and interpreting data from geographic objects on the Earth's surface (Latue, 2023). This analysis uses scoring and overlays tools in ArcGIS to create disaster risk maps in Ijen Sub-District. The level of disaster risk is obtained from measurements of the hazard, vulnerability, and capacity of the flash flood disaster, which were calculated in advance. The weights used in calculating each disaster indicator are based on adjustments made by the researchers in accordance with regional characteristics and a review of relevant literature.

2.3.2. Delphi analysis

Delphi analysis is a data processing process based on the opinions of experts; in this case, disaster experts. This analysis is used to determine the appropriate flash flood mitigation activities in Ijen Sub-District. Data were collected in the Delphi analysis via a Likert scale with values ranging from 1 to 4 in the order of strongly disagree, disagree, agree, and strongly agree. The criteria are that the standard deviation of all experts must be < 1.5 and the interquartile range of all expert sources must be < 2.5. If both criteria are met, consensus is reached, or the results are said to be convergent. However, if either criterion is not met, consensus is not reached, or the results are said to be divergent (Rawie & Rofii, 2024). In this analysis, several rounds were carried out to reach an agreement among the six selected experts who understood the disaster and research locations.

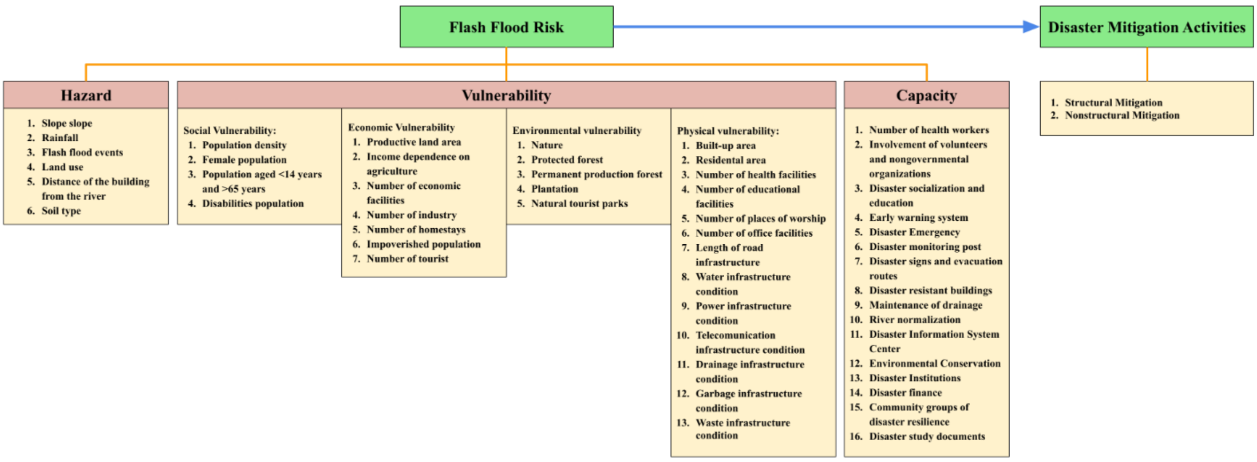

Figure 3. Research Variable

Source: (Badan Nasional Penanggulangan Bencana, 2018; BPBD Kabupaten Bondowoso, 2023; Destirani et al., 2020; Devita et al., 2022; Lestari, 2021; Maharani et al., 2020; Pahleviannur et al., 2023; Peraturan Daerah Nomor 3 Tahun 2024 Tentang Rencana Tata Ruang Wilayah Kabupaten Bondowoso Tahun 2024 - 2044, 2024; Peraturan Kepala Badan Nasional Penanggulangan Bencana Nomor 02 Tahun 2012 Tentang Pedoman Umum Pengkajian Risiko Bencana, 2012; Rahmawati et al., 2024; Ramadhan et al., 2024; Susanti et al., 2023; Ujung et al., 2019)

Table 1 Parameters of the Flash Flood Hazard

Data	Category			Information	Classification	Weight
	Low	Medium	High			
Slope	0 – 15%	15 – 40%	> 40%	Area with slope <15% is 103.612.600 m²	Low	
				Area with slope 15 - 40% is 36.574.400 m²	Medium	0,25
				Area with slope >40% is 78.940.000 m²	High	
Rainfall	≤1.500 mm/years	1.501 – 2.000 mm/years	≥2.000 mm/years	1.500 – 2.000 mm/years	Medium	0,3
Flash flood incident	There are no incidents in 5 years	1 – 3 incidents in 5 years	>3 incidents in 5 years	3 incidents in 5 years	Medium	0,05
Land use	Forest	Plantation	Residential/industrial	140.153.300 m² as forest	Low	
				77.448.500 m² as plantation	Medium	0,2
				1.533.700 m² as residental / industrial	High	
Distance of the building from the river	>500 m	50 – 500 m	<50 m	Area located >500 m from river is 109.913.000 m²	Low	
				Area located 50 - 500 m from river are 83.758.500 m²	Medium	0,05
				Area located <50 m from river is 25.463.900 m²	High	
Soil type	Alluvial, planosol, gray hydromorphic, groundwater latic	Asos, brown andosol and gray regosol	Yellowish brown andosol, reddish-brown latosol, gray regosol and lithosol complex	67.800 m² of Asos, brown andosol and gray regosol	Medium	0,15
				219.067.600 m² of yellowish-brown andosol, reddish-brown latosol, gray regosol and lithosol complex	High	

(BPBD Kabupaten Bondowoso, 2023; Rahmanizah et al., 2023; Susanti et al., 2023)

RESULT AND DISCUSSION

3.1. Risk of Flash Floods

3.1.1. Hazard

Hazards are potential disasters that can cause losses in the form of casualties, property damage, infrastructure damage, and environmental damage. Hazards do not always present risk; risk depends on disaster management in an area. A higher hazard will increase the potential for disaster risk. The results of the parameters and the determination of the flash flood hazard class used in this study can be seen in Table 1 and Figure 4.

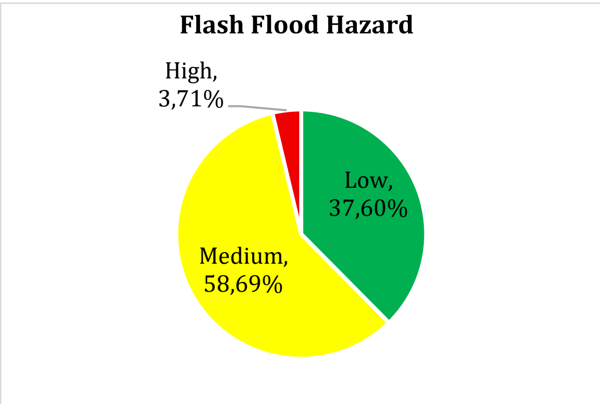

Figure 4. Class of Flash Flood Hazard

Table 1 and Figure 3 show that the results of the 6 (Six) parameters of flash flood hazard in Ijen Sub-District can be divided into 3 classifications. The lower class of parameters consists of slopes of 0–15%, forestland use, and the distance of buildings from the river >500 meters. The medium class of parameters consists of slopes of 15–40%, rainfall of 1.501–2.000 mm/year, 3 flood incidents in 5 years, plantation land use, building distance from the river 101–500 meters, and soil types such as brown andosol and gray regosol. The high-class parameters consist of slope >40%, residential or industrial land use, building distance from the river ≤100 meters, and yellowish-brown andosol soil type; gray and lithosol regosol complex; and reddish-brown latosol. The flash flood hazard level was 37.6% in the low class, 58.69% in the medium class, and 3.71% in the high class. It can be concluded that the medium class dominates the level of flash flood hazard in Ijen Sub-District. A map of the flash flood hazard in Ijen Sub-District is shown in Figure 5.

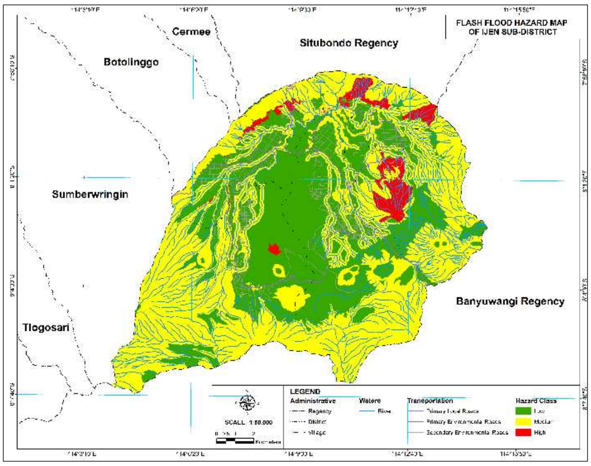

Figure 5. Flash Flood Hazard Map of Ijen Sub-District

3.1.2. Vulnerability

Vulnerability is one of the components of disaster risk related to the conditions or characteristics of the community in facing and overcoming disasters. The components of disaster vulnerability are divided into social, economic, physical, and environmental conditions.

A. Social Vulnerability

Social vulnerability is a component related to the ability and development of communities around disaster areas. The parameters of social vulnerability to flash floods in Ijen Sub-District are shown in Table 2.

Table 2 shows that the 4 (Four) social vulnerability parameters of flash floods in Ijen Sub-District can be divided into 3 classifications. The parameters in the lower class are population density and the disabled population. The parameter in the medium class is the population age. The parameter in the high class is the female population.

B. Economic Vulnerability

Economic vulnerability is a component related to the local community's economic structure or source of income (Ujung et al., 2019). The parameters of economic vulnerability to flash floods in Ijen Sub-District are shown in Table 3.

Table 3 shows that the 7 (Seven) economic vulnerability parameters of flash floods in Ijen Sub-District can be divided into 3 classifications. The parameters in the lower class include industry and the impoverished population. The parameters in the medium class consist of income dependence on agriculture and homestays. The parameters in the high class include productive land area, economic facilities, and tourists.

C. Physical Vulnerability

Physical vulnerability is a component related to physical structure that can affect the diversity of local community activities (Ujung et al., 2019). The parameters of physical vulnerability to flash floods in Ijen Sub-District are shown in Table 4.

Table 4 shows that the 13 (Thirteen) physical vulnerability parameters of flash floods in Ijen Sub-District can be divided into 3 classifications. The parameters in the lower class consisted of built-up areas, residential areas, and water infrastructure conditions. The parameters in the medium class include power infrastructure conditions, telecommunication infrastructure conditions, drainage infrastructure conditions, and waste infrastructure conditions. The parameters in the high class include health facilities, educational facilities, places of worship, office facilities, road length, and garbage infrastructure conditions.

Table 2. Parameters of Social Vulnerability

Data	Category			Information	Classification	Weight
	Low	Medium	High			
Population density	<500 jiwa/km^2	500 – 1.000 jiwa/km^2	>1.000 jiwa/km^2	55,15 people/ km^2	Low	0,4
Female population	<20%	20 – 40%	>40%	49,95 % (6.009 people)	High	0,1
Population age <14 years and >65 years	<20%	20 – 40%	>40%	29,8 % (3,585 people)	Medium	0,2
Disabilities population	<1%	1 – 2%	>2%	0,68% (82 people)	Low	0,3

(Devita et al., 2022; Endah Puspitotanti & Karmilah, 2021; Maharani et al., 2020; Peraturan Kepala Badan Nasional Penanggulangan Bencana Nomor 02 Tahun 2012 Tentang Pedoman Umum Pengkajian Risiko Bencana, 2012; Ujung et al., 2019)

Table 3. Parameters of Economic Vulnerability

Data	Category			Information	Classification	Weight
	Low	Medium	High			
Productive land area	< 30%	30 – 50%	> 50%	133.480,400 m^2 (60,91%)	High	0,25
Income dependence on agriculture	< 30% in agricultural sector	30 – 50% in agricultural sector	> 50% in agricultural sector	4.726 people (39,29%)	Medium	0,2
Number of economic facilities	≤ 5 units	6 – 15 units	> 15 units	40 units	High	0,1
Number of industry	≤ 5 units	6 – 15 units	> 15 units	2 units	Low	0,1
Number of homestays	≤ 5 units	6 – 15 units	> 15 units	8 units	Medium	0,05
Impoverished population	< 10% total population	10 – 30% total population	> 30% total population	1,23% (146 people)	Low	0,2
Number of tourists	<10.000 tourists	10.000 – 100.000 tourists	>100.000 tourists	223.806 tourists	High	0,1

(Devita et al., 2022; Pahleviannur et al., 2023; Peraturan Kepala Badan Nasional Penanggulangan Bencana Nomor 02 Tahun 2012 Tentang Pedoman Umum Pengkajian Risiko Bencana, 2012; Ujung et al., 2019)

Table 4. Parameters of Physical Vulnerability

Data	Category			Information	Classification	Weight
	Low	Medium	High			
Built-up area	< 40% area	40 – 75% area	> 75% larea	2.546.900 m² (1,16%)	Low	0,2
Residential area	<30% area	30 – 60% area	> 60% area	1.436.900 m² (0,66%)	Low	0,15
Number of health facilities	≤ 3 units	4 – 6 units	> 6 units	25 units	High	0,05
Number of educational facilities	≤ 3 units	4 – 6 units	> 6 units	21 units	High	0,05
Number of places of Worship	≤ 3 units	4 – 6 units	> 6 units	23 units	High	0,05
Number of office facilities	≤ 3 units	4 – 6 units	> 6 units	23 units	High	0,05
Length of road infrastructure	<100 km	100 – 200 km	>200 km	332,21 km	High	0,15
Water infrastructure condition	Widely available, easily accessible, and of good quality	Available but with limited access; the quality is fairly good	Limited or no access, with poor water quality	People can easily get access to clean water of good quality because it is near the source of water and is obtained through wells	Low	0,05
Power infrastructure conditions	The electricity supply is very stable, and there is backup infrastructure in place	Available and relatively stable, but there is a risk of outages due to weather conditions	The electricity supply is unstable and there are frequent outages	There is a stable power infrastructure, but it can be blacked out due to weather or disasters	Medium	0,05
Telecommunication infrastructure conditions	Stable and consistent tele-communications signals	A tele-communications signal is available but unstable	Limited or no signal access	There is a telecommunication infrastructure with the strongest signal conditions in the center of the government and distributed in settlements. However, in tourism areas and plantations, has weak signals. Only one mobile telecommunication company can reach an evenly distributed that is Telkomsel	Medium	0,05
Drainage infrastructure conditions	Conditions that allow water to flow quickly without clogging	The condition is adequate, but there is still a blockage	It is unable to handle the flow of rainwater and is frequently clogged	There are drainage systems near settlements that can hold rainwater. However, the basic condition of drainage requires cleaning because there are plants and garbage	Medium	0,05
Garbage infrastructure conditions	TPS/TPA sites are located away from flood-prone areas and equipped with recycling systems	TPS/TPA at this location is quite prone to flooding	TPS/TPA is inadequate, causing trash to pile up in drainage channels and on the streets	Unavailable TPS/TPA in Ijen Sub-District. The management is limited to garbage cans that will be transported by BUMDES to the nearest polling station every week. It is common for people to choose to burn and throw garbage into the river	High	0,05
Waste infrastructure conditions	Large-capacity channels separated by waterways	Small-capacity pipes that may contaminate waterways	The channel is connected to the waterway	Waste from industry already has its own waste management technology. However, there is still household and livestock waste dumped into the river	Medium	0,05

(Peraturan Kepala Badan Nasional Penanggulangan Bencana Nomor 02 Tahun 2012 Tentang Pedoman Umum Pengkajian Risiko Bencana, 2012; Ujung et al., 2019)

D. Environmental Vulnerability

Environmental vulnerability is a component related to land cover in maintaining ecosystem balance and human survival. The parameters of environmental vulnerability to flash floods in Ijen Sub-District are shown in Table 5.

Table 5 shows that the 5 (Five) environmental vulnerability parameters of flash floods in Ijen Sub-District can be divided into 2 classifications. The parameters in the lower class include nature, permanent production forests, and natural tourist parks. The parameters in the medium class consist of protected forests and plantations. There is no parameter in the high class.

The vulnerability of flash floods in Ijen Sub-District is generated from the calculation of four existing vulnerability components via Equation 1. The vulnerability class can be seen in Figure 6.

$$\begin{aligned} &Flash\ flood\ Vulnerability \\ &= (0.4\ x\ Social\ Vulnerability\ Score) \\ &+\ (0.25\ x\ Economic\ vulnerability\ score) \\ &+\ (0.25\ x\ Physical\ vulnerability\ score) \\ &+\ (0.1\ x\ Environmental\ vulnerability\ score) \qquad (1) \end{aligned}$$

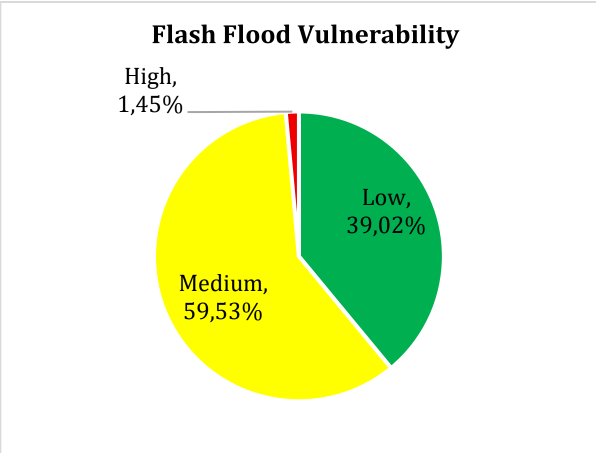

Figure 6. Class of Flash Flood Vulnerability

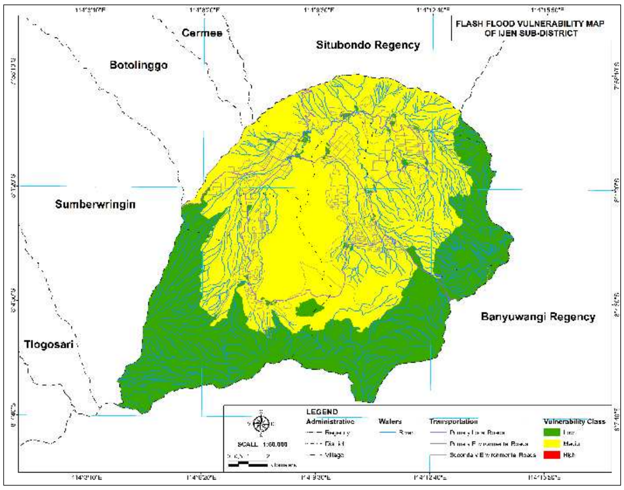

Figure 7. Flash Flood Vulnerability Map of Ijen Sub-District

Based on the results of Equation 1 and Figure 5, the flash flood vulnerability in Ijen Sub-District can be divided into 3 classes. The classes of flash flood vulnerability included 39.02% in the low class, 59.53% in the medium class, and 1.45% in the high class. It can be concluded that the medium class dominates the level of flash flood vulnerability in Ijen Sub-District. A map of flash flood vulnerability in Ijen Sub-District is shown in Figure 7.

3.1.3. Capacity

Capacity is the ability of a region to deal with future disasters. A higher capacity decreases the level of disaster risk. The parameters of flash flood capacity in Ijen Sub-District is shown in Table 6.

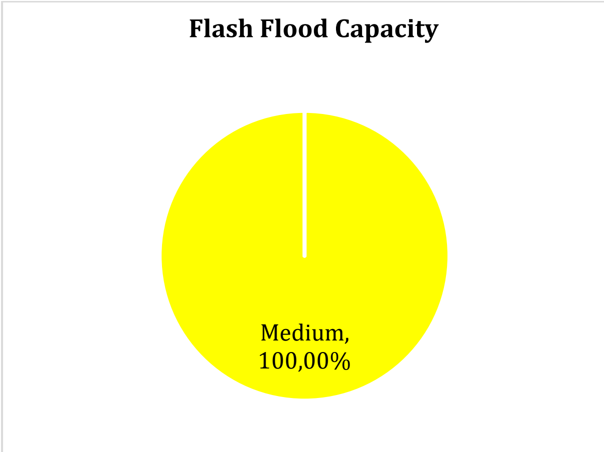

Figure 8 Class of Flash Flood Capacity

Figure 8 shows that 16 (Sixteen) capacity parameters that have been described are processed by scoring and overlay techniques and produce 1 (one) class of capacity, which is a medium of 100% of the entire area. The parameters are divided into 3 (Three) classifications. The parameters in the lower class include disaster emergencies, disaster monitoring posts, disaster-resistant buildings, and river normalization activities. The parameters in the medium class consist of disaster socialization and education, drainage maintenance, environmental conservation, and disaster study documents. The parameters in the high class include health workers, volunteers, early warning systems, disaster signs, disaster information system centers, disaster institutions, disaster finance, and community groups. A map of flash flood capacity in Ijen Sub-District is shown in Figure 9.

Table 5. Parameters of Environmental Vulnerability

Data	Category			Value	Classification	Weight
	Low	Medium	High			
Nature	<15%	15 – 50%	>50%	9.373.200 m^2 (4,28%)	Low	0,25
Protected forest	<30%	30 – 50%	>50%	73.142.300 m^2 (33,38%)	Medium	0,25
Permanent production forest	<30%	30 – 50%	>50%	56.031.800 m^2 (25,57%)	Low	0,2
Plantation	<20%	20 – 50%	>50%	77.448.500 m^2 (35,34%)	Medium	0,15
Natural Tourist Parks	<15%	15 – 50%	>50%	1.533.000 m^2 (0,7%)	Low	0,15

(Peraturan Kepala Badan Nasional Penanggulangan Bencana Nomor 02 Tahun 2012 Tentang Pedoman Umum Pengkajian Risiko Bencana, 2012; Ujung et al., 2019)

Table 6. Parameters of Capacity

Data	Category			Information	Classification	Weight
	Low	Medium	High			
Number of health workers	≤ 10 people	11 – 30 people	> 30 people	40 people	High	0,05
Involvement of volunteers and non-governmental organizations in disaster management	None	There were cases where the response time exceeded 6 hours after the disaster occurred	It responds within 6 hours of a disaster and actively conducts disaster education activities	Available and provide a quick response with arrival within 6 hours. The volunteers who came were community members in the Tapal Kuda area by assisting with disaster evacuation, recovery, and education.	High	0,05
Disaster socialization and education	None	These activities are conducted < 2 times a year for communities in disaster-prone areas	These activities are conducted ≥ 2 times a year for communities in disaster-prone areas	Socialization from the government is carried out once a year before the rainy season. However, this number does not meet the standards of BNPB.	Medium	0,05
Early warning system	None	There are detection devices, but they are not complete they consist of sensors or transmitters	There is a full set of disaster detection equipment consisting of sensors and transmitters	There are in an evenly distributed number. The system is in the form of flood sensors around Afdeling Ijen and flood sirens in front of the Ijen Village Hall	High	0,05
Disaster Emergency	None	It exists, but it does not yet meet the BNPB's basic disaster response equipment standards.	The equipment is available and meets the BNPB's basic disaster response standards	No disaster safety equipment is currently available in the disaster-affected area	Low	0,05
Disaster monitoring post	None	They exist, but they are located in disaster-prone areas and are difficult to access	It is located in an area that is safe from disasters and easily accessible	There are no disaster monitoring posts yet	Low	0,05
Disaster signs and evacuation routes	None	Located in a disaster-prone area, but the necessary infrastructure is incomplete—including signs indicating the disaster-prone area, assembly points, evacuation routes, evacuation sites, or directional signs	Located in disaster-prone areas and fully equipped with signs indicating disaster-prone zones, assembly points, evacuation routes, evacuation sites, and directional signs	It is in a strategic location and distributed in Ijen Village and Kalisat Village in the form of flood danger area signs, evacuation routes, directions, evacuation places, and gathering points	High	0,05
Disaster resistant buildings	None	It exists, but is applied to < 50% of buildings	Exists and is implemented in ≥ 50% of buildings	There are no disaster-resistant buildings yet	Low	0,05
Maintenance of drainage/ embankments/ reservoirs	None	It is performed < 2 times a year	Exists and is performed regularly ≥ 2 times a year	Drainage maintenance has been carried out, but only after a disaster has occurred. There are no activities to maintain the drainage regularly	Medium	0,05
River normalization activities	None	It is done, but not on a regular basis every year before the rainy season	It takes place and is carried out regularly every year before the rainy season	River area normalization activities have not yet been carried out	Low	0,05
Disaster Information System Center	None	There is a problem with the slow dissemination of disaster information when a disaster occurs	Available and capable of disseminating accurate and timely disaster information when a disaster occurs	The Regional Disaster Management Agency of Bondowoso Regency has a special disaster application called SI-GABAN (Disaster Response Information System) in collaboration with the Communication and Information Service. This application functions as a media for reporting and presenting disaster-prone areas in Bondowoso Regency.	High	0,05

Data	Category			Information	Classification	Weight
	Low	Medium	High			
Environmental Conservation	None	Plant maintenance is required < 2 times a year	Includes plant maintenance ≥ 2 times a year	Reforestation activities have been carried out for 3 (three) years starting in 2020 by Perum Perhutani in collaboration with the police, army, and the local community. This activity is carried out between the slopes of Mount Raung and Mount Suket. However, this activity is no longer carried out because it is considered safe.	Medium	0,05
Disaster Institutions	None	Response to the disaster was delayed by more than 6 hours	Be on-site and respond quickly to disasters within 6 hours	Represented by the Regional Disaster Management Agency, which actively monitors through the EWD Application, coordinates with district stakeholders and members of Destana (Disaster Resilient Village Community), conduct disaster education, and provide a quick response within 6 hours.	High	0,1
Disaster finance	There are no disaster reserves, and the region relies on outside assistance	There is a disaster reserve fund derived from limited local government revenue	There is a disaster reserve fund drawn from local government revenue and sustainable funding	Separate sources of disaster funds come from the Regional Revenue and Expenditure Budget (APBD) and the National Disaster Management Agency (BNPB)	High	0,05
Community groups of disaster resilience	None	Doesn't conduct regular disaster risk assessments, risk reduction, and capacity-building for villages	Conduct risk assessments, risk reduction, and capacity-building for villages to cope with disasters at least once a year	There is a name called Destana (Disaster Resilient Village) which has been formed since 2024 and is actively monitored with BPBD. Destana is a pioneer in disaster management in the local area. The responsibility of providing education to the surrounding community regarding disasters, disaster indicators, and disaster evacuation.	High	0,05
Disaster study documents	None	Data is available, but it is incomplete across all disaster categories	Complete data is available for all disaster categories,	There are disaster study documents, but found incomplete data about calculation of total vulnerability and regional capacity in addition to referring to the East Java Province BPBD study.	Medium	0,2

(Ramadhan et al., 2024; Ujung et al., 2019)

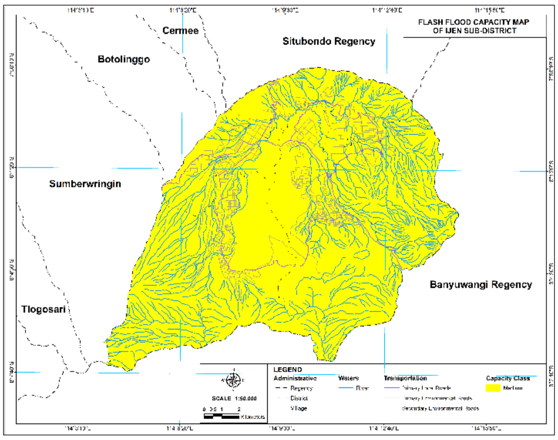

Figure 9. Flash Flood Capacity Map of Ijen Sub-District

3.1.4. Risk

Risk is a potential disaster that becomes a reality. Disaster risk is calculated on the basis of the results of the calculation between hazard and vulnerability, divided by capacity. The disaster risk equation used is shown in Equation 2, or processed with overlay techniques in *ArcGIS* software. The results of the risk class are shown in Figure 10.

$$R \approx H\ x \frac{V}{C} \quad \text{.........} \ (2)$$

Information:
R = Risk
H = Hazard
V = Vulnerability
C = Capacity

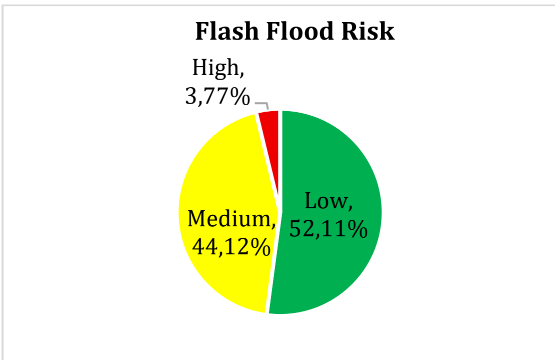

Figure 10. Class of Flash Flood Risk

Figure 10 shows that the calculation of hazard, vulnerability, and capacity generates the risk level of flash floods in Ijen Sub-District. The results of this study indicate an increase in the flash flood risk in Ijen Sub-District compared to the Disaster Risk Assessment of Bondowoso Regency in 2023. Although both reports indicate that most of the area is at a low risk level, there has been a decrease from 312.3 ha (98.83%) to 52,11%. The area classified as medium risk has increased from 2,77 ha (0.87%) to 44,12%. Meanwhile, the area classified as high risk, which was not previously identified, has increased to 3,77%.

The high-risk areas for flash floods in Ijen Sub-District are spread across all villages. Details of high-risk areas in Jampit cover 370.435 m^2, Kali Gedang covers 2.877.665 m^2, Kalianyar covers 42.109 m^2, Sumber Rejo covers 4.015.364 m^2, Kalisat covers 683.824 m^2, and Sempol covers 278.279 m^2. Although Kali Gedang has the largest high-risk area, historical data show that three flash flood events in Ijen Sub-District occurred in Sempol and Kalisat. Based on interview results, water flows from the steep upper reaches of Mount Raung and Mount Suket, passing through plantation areas that cannot adequately absorb and retain excess water, causing it to move rapidly toward residential areas. Therefore, high-risk areas located near settlements and infrastructure require improved disaster resilience. In the post-disaster, damaged houses and mud-submerged village roads have been cleaned and repaired, as shown in Figure 11 and Figure 12.

Figure 11. Post-Disaster Housing

Figure 12. Post-Disaster Road

The prevalence of low-risk cases in Ijen Sub-District is due to several factors. First, forest-dominated land cover can increase rainwater absorption and reduce erosion. Second, the low population density and the concentration of settlements in gentle valley areas will reduce vulnerability to the impacts of disasters. Third, strengthening local capacity to respond to disasters through Disaster-Resilient Village (Destana) groups and mitigation infrastructure. A map of flash flood disaster risk in Ijen Sub-District is shown in Figure 13, and a map of high-risk flash flood areas with settlements and roads in Ijen Sub-District is shown in Figure 14.

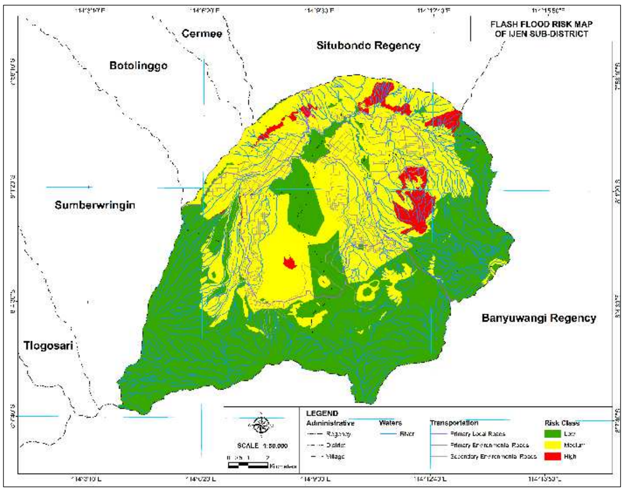

Figure 13. Flash Flood Risk Map of Ijen Sub-District

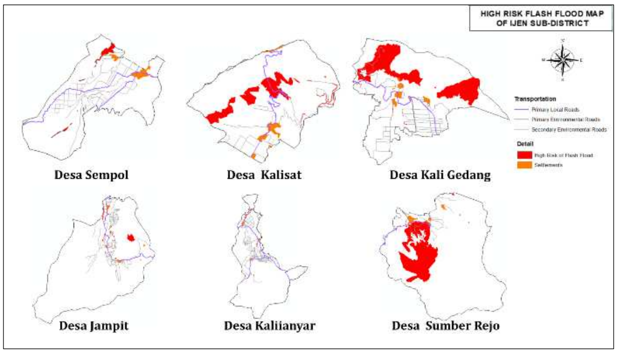

Figure 14. High Risk Flash Flood Map of Ijen Sub-District

3.2. Mitigation Activities of Flash Flood

Delphi analysis, which consists of 2 rounds of iteration to reach an agreement, is used to determine flash flood disaster mitigation activities. The criteria for the first round are based on the direction of the Regional Spatial Plan (RTRW) of Bondowoso Regency for 2024–2044. Moreover, the second round of criteria is based on the results of the first round of questionnaires and input from experts. The experts in the questionnaire consist of:

a. R1: Staff in the field of infrastructure and regional development at the Regional Development Planning, Research, and Development Agency of Bondowoso Regency.
b. R2: Staff in the field of spatial planning and land management at the Housing, Residential Areas, Cipta Karya, and Spatial Planning of Bondowoso Regency.
c. R3: Staff in the prevention and preparedness section at the Regional Disaster Management Agency of Bondowoso Regency.
d. R4: Staff of the Ijen Sub-District office.
e. R5: Lecturer in hydrology at the University of Jember.

f. R6: Private Sector (Consultants or contractors who have previously carried out disaster mitigation activities in Sempol Subdistrict).

The table of the first round of Delphi analysis can be seen in Table 7.

In the results of the first round of Delphi analysis, 5 (five) criteria were divergent, and 5 (five) criteria were convergent. The five criteria that divergent with irrigation, drainage, waste facilities, green open spaces, and infiltration wells. Irrigation is irrelevant because there is no agricultural land in the form of rice fields in Ijen Sub-District. Waste facilities are irrelevant because they are not the main cause of flash floods in the Ijen Sub-District. Green open spaces, drainage, and infiltration wells are irrelevant because they are less able to accommodate the capacity of flash floods with large volumes of water at high speeds. The table of the second round of Delphi analysis is shown in Table 8.

Table 7. First Round of Delphi Analysis

Criteria	Respondent						Mean	St.Dev	IR	Information
	1	2	3	4	5	6				
Structural Mitigation										
Vertical building	1	3	4	1	3	3	2,50	1,22	1,5	Convergent
Open space	1	4	2	1	4	3	2,50	1,38	2,5	Divergent
Maintaining existing irrigation channels	1	4	4	1	2	4	2,67	1,51	2,75	Divergent
Drainage channels	1	4	1	4	2	4	2,67	1,51	2,75	Divergent
Provision of infiltration wells in High-density areas	1	2	4	1	1	4	2,17	1,47	2,5	Divergent
Waste facilities	1	3	1	4	2	4	2,50	1,38	2,5	Divergent
Build a place for disaster monitoring and evacuation	4	4	4	4	2	3	3,50	0,84	0,75	Convergent
Non-Structural Mitigation										
Implementation of a study on flash flood risk reduction	4	4	4	4	4	4	4,00	0,00	0,00	Convergent
Control of cultivated areas in flash flood prone areas	4	4	4	4	4	4	4,00	0,00	0,00	Convergent
Socialization and empowerment of community	4	4	4	4	4	4	4,00	0,00	0,00	Convergent

Source: Data processing, 2025

Table 8. Second Round of Delphi Analysis

Criteria	Respondent						Mean	St.Dev	IR	Information
	1	2	3	4	5	6				
Structural Mitigation										
Sabo DAM or ground sills	3	4	3	4	4	4	3,67	0,52	0,75	Convergent
Disaster-proof buildings	4	4	4	4	3	3	3,67	0,52	0,75	Convergent
Vertical building	3	3	3	3	3	3	3,00	0,00	0	Convergent
Settlement not in riverbank areas or steep slopes	4	3	4	3	4	3	3,50	0,55	1	Convergent
A place for disaster monitoring and evacuation	4	4	4	4	2	3	3,50	0,84	0,75	Convergent
Non-Structural Mitigation										
Spatial planning	4	4	4	4	4	4	4,00	0,00	0	Convergent
A study on flash flood risk reduction	4	4	4	4	4	4	4,00	0,00	0	Convergent
Control of cultivated areas in flash flood prone areas	4	4	4	4	4	4	4,00	0,00	0	Convergent
Controlling land use change	4	4	3	4	4	4	3,83	0,41	0	Convergent
Socialization and empowerment of community	4	4	4	3	4	4	3,83	0,41	0	Convergent
Collaboration of disaster resilient community with tourism managers	4	4	4	4	4	3	3,83	0,41	0	Convergent
Environmental conservation activities	3	4	4	4	4	4	3,83	0,41	0	Convergent
Vegetation arrangement	3	4	4	4	4	4	3,83	0,41	0	Convergent
River normalization	4	4	4	4	4	4	4,00	0,00	0	Convergent
Disaster safety equipment	3	4	4	4	2	4	3,50	0,84	0,75	Convergent

Source: Data processing, 2025

Table 9. Mitigation Activities

No	Mitigation Activities	Time Period		
		Short-Term	Medium-Term	Long-Term
Structural Mitigation				
1	Construction of sabo DAM or ground sills to control water flow		■	
2	Construction of disaster-resistant buildings with strong foundations, waterproof materials, and adaptive designs to protect its occupants		■	
3	Development of buildings directed vertically in residential, office, and commercial areas			■
4	Construction of settlements not in riverbank areas and steep slopes to provide a sense of security to the community			■
5	Establishment of buildings for monitoring and disaster evacuation located in strategic and flood-prone areas to enhance community preparedness		■	
Non-Structural Mitigation				
1	Spatial planning based on disaster mitigation by integrating disaster risk aspects in the efforts of land use and control.			■
2	Implementation of studies on flood disaster risk reduction efforts.	■		
3	Control of built cultivation areas in flood-prone areas with provisions for limiting development and providing supporting infrastructure for disaster mitigation.		■	
4	Control of land use changes by establishing protected zones, controlling forest conversion, and mandatory AMDAL for projects and activities carried out.		■	
5	Implementation of socialization and empowerment of community preparedness periodically in the form of identifying disaster warning signs, flood-prone areas, risk reduction actions, introduction of disaster emergency equipment, disaster evacuation simulations, and responding to early warnings.	■		
6	Collaboration between disaster-resilient community groups and local tourism managers through the dissemination of information and disaster training to provide a sense of security to tourists	■		
7	Procurement of environmental conservation activities through reforestation to maintain environmental sustainability.		■	
8	Regulation of vegetation to control water flow speed and soil erosion, such as land patterns and commodities for forests, community plantations, and other seasonal crops.		■	
9	Routine river normalization activities, especially in upstream areas, in the form of widening river bodies, deepening rivers, tidying river shapes, and strengthening riverbeds and banks to reduce erosion	■		
10	Provision of disaster safety equipment to minimize casualties in the form of first aid kits, long-lasting snacks, whistles, bathing equipment, communication tools, and spare clothing.	■		

The results of the second round of Delphi analysis on 15 (fifteen) criteria were obtained. The fulfillment of all the conditions and the lack of input related to additional criteria from experts indicate that a consensus has been reached in determining disaster mitigation activities. These disaster mitigation activities can provide a recommendation for the government in developing disaster management strategies that are more direct, effective, and sustainable. Flash flood mitigation activities in Ijen Sub-District include structural mitigation and non-structural mitigation as shown in Table 9.

4. CONCLUSION

Ijen Sub-District has experienced three incidents of flash floods in 2020– 2024 caused by heavy rainfall and changes in land use. However, there are inconsistencies, as the Bondowoso Regency spatial planning document classifies it predominantly in the low risk level of flash floods. Still, the East Java Provincial spatial planning document classifies Bondowoso Regency in the high-risk level of flash floods. The results of the spatial analysis indicate that the flash flood risk levels in Ijen Sub-District consist of the low class at 52.11%, the medium class at 44.12%, and the high class at 3.77%. The dominance of the lower class was caused by land cover, population density, a concentrated distribution of settlements, disaster community, and mitigation infrastructure. Delphi analysis recommended 15 flash flood disaster mitigation activities, divided into structural and non-structural mitigation for short-term, medium-term, and long-term implementation. In future research, it is recommended to assign weights measurably and include expert respondents to broaden the perspective on disaster mitigation activities.

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